Turbulence and Inflow Analyses

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FY05 Implementation Meeting

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Outline

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- Objectives
- Approach
- Specific Activities
- Schedule
- Status
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- Initial Conclusions & Current Thoughts

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Background

- Organized or coherent turbulence is often responsible for increased structural loading of wind turbines and is a likely source of the higher than predicted loads seen on early multi-megawatt turbines
- The increased size and operating heights of future LWST turbines makes them more flexible and sensitive to coherent turbulence structures generated by Kelvin-Helmholtz instability
- Nocturnal low-level jet streams are responsible for generating coherent inflow turbulence at the heights to be occupied by LWST rotors as confirmed by the Lamar Low-Level Jet Program
- The initial release of the Alpha Version of the new *TurbSim* inflow simulation code incorporating coherent structures was made in July 2004

Approach

- Analyze the structural response of turbines in order to identify the primary turbulent flow properties that are responsible
- Incorporate facsimiles of these properties in numerical inflow simulations as accurately as possible within the imposed constraints

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Objectives

- To document the impacts of coherent turbulence on wind turbine structures
- To improve existing numerical simulations to include coherent turbulent structures that induce loading events that will impact the longevity and operational reliability of turbine designs meeting the DOE LWST Program goals
- To provide criteria important for site specific design and locating of LWST turbines

Specific Activities

- Compare the character of coherent flow events generated by LES and DNS simulations of a breaking KH Billow
- Develop a methodology to include coherent elements derived from these simulations in the *TurbSim* inflow turbulence code
- Document the impact of coherent turbulence structures on turbine response using simulations of the ART and the virtual WindPACT turbine
- Validate by comparing actual ART upwind array measured inflows and turbine response with *TurbSim*-generated inflows using A. Wright's FAST model
- Complete the processing of the Lamar Low-Level Jet Project data and use results in scaling the *TurbSim* simulations for turbines installed beneath low-level jet streams

Schedule

- Issue an updated version of the *TurbSim* Code (November 2004) which improves the incorporation of coherent structures (based on ART inflow data)
- Prepare a report summarizing the impacts of coherent turbulence and its simulation using ART upwind array inflow data (January 2005)
- Complete the processing of the Lamar Low-Level Jet Project data (June 2005)
- Analyze the Lamar data and incorporate any scaling reflective of that environment in the *TurbSim* code (September 2005)
- Consider hosting a workshop in the use of *TurbSim* (September 2005)

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Status

- Release of updated version of alpha version of *TurbSim* to be made within two weeks which improves incorporation of coherent structures
- Comparison of LES and DNS versions of KH Billow simulation on turbine response is nearing completion supported by contractor Colorado Research Associates
- Processing of Lamar data has been postponed in order to accommodate the effort to improve the *TurbSim* code and make it available as soon as possible

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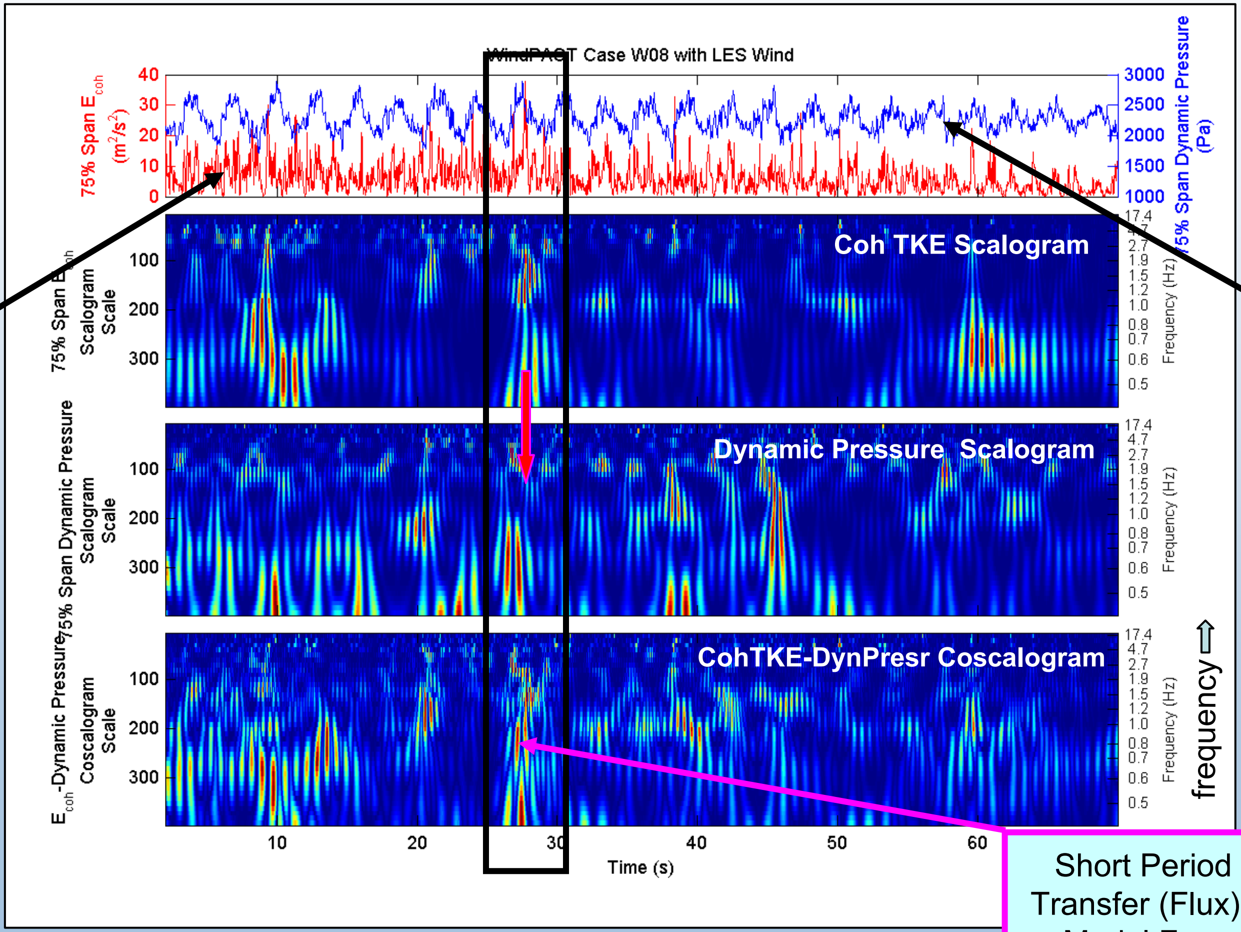
Recent Results

- Comparison of IEC Normal Turbulence Model (NTM) with Smooth Terrain Model and KH Billow Inflow Excitations of WindPACT Turbine
- The *TurbSim* Stochastic Inflow Simulator Code

Wavelet Analysis of Interaction Between Local Coherent Turbulence & Blade Dynamic Pressure

Breaking LES KH Billow

Coherent TKE at Blade Station



Local Blade 1 Dynamic Pressure at 75% Blade Radius

Short Period Energy Transfer (Flux) to Blade Modal Frequencies

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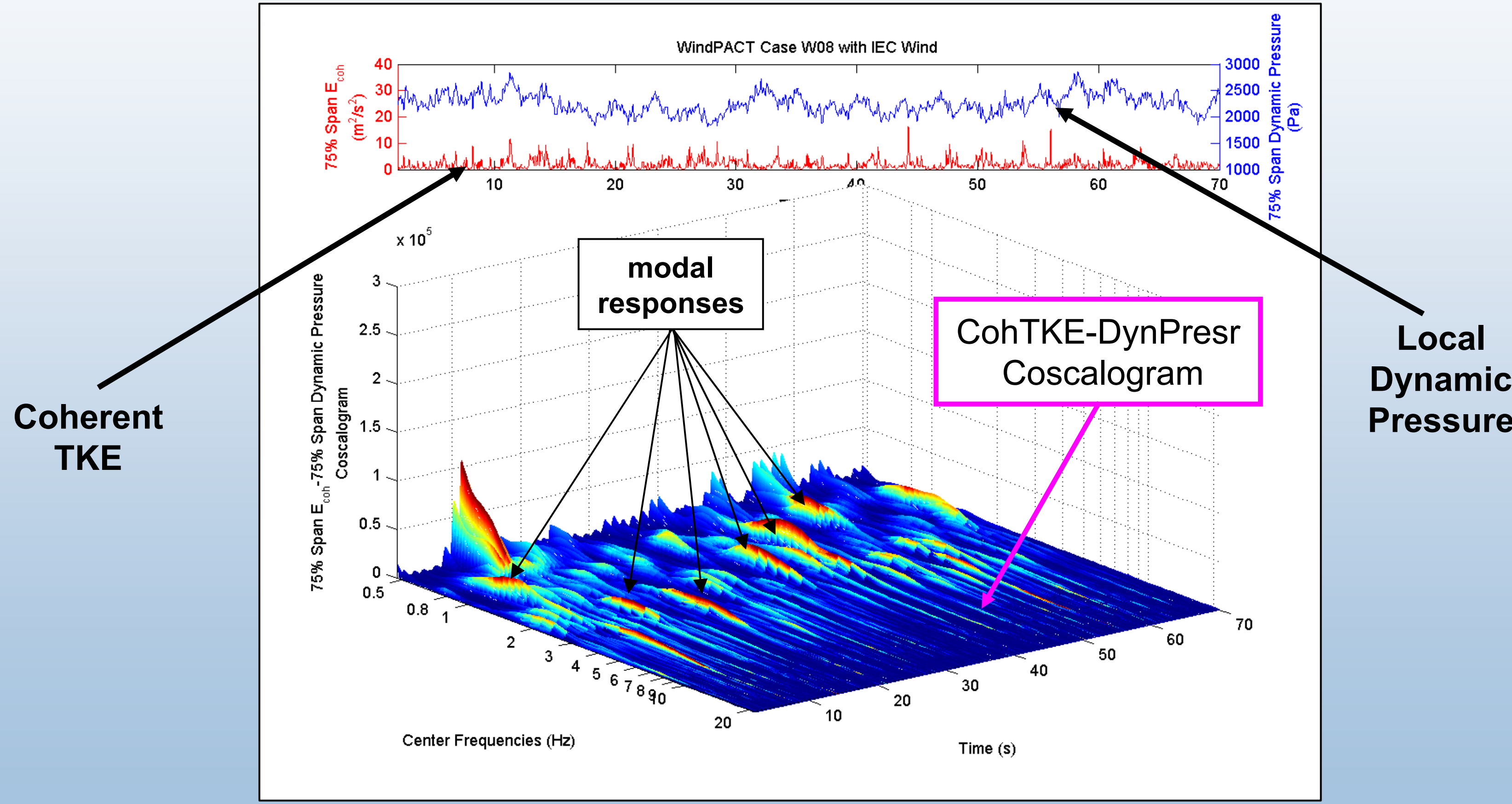
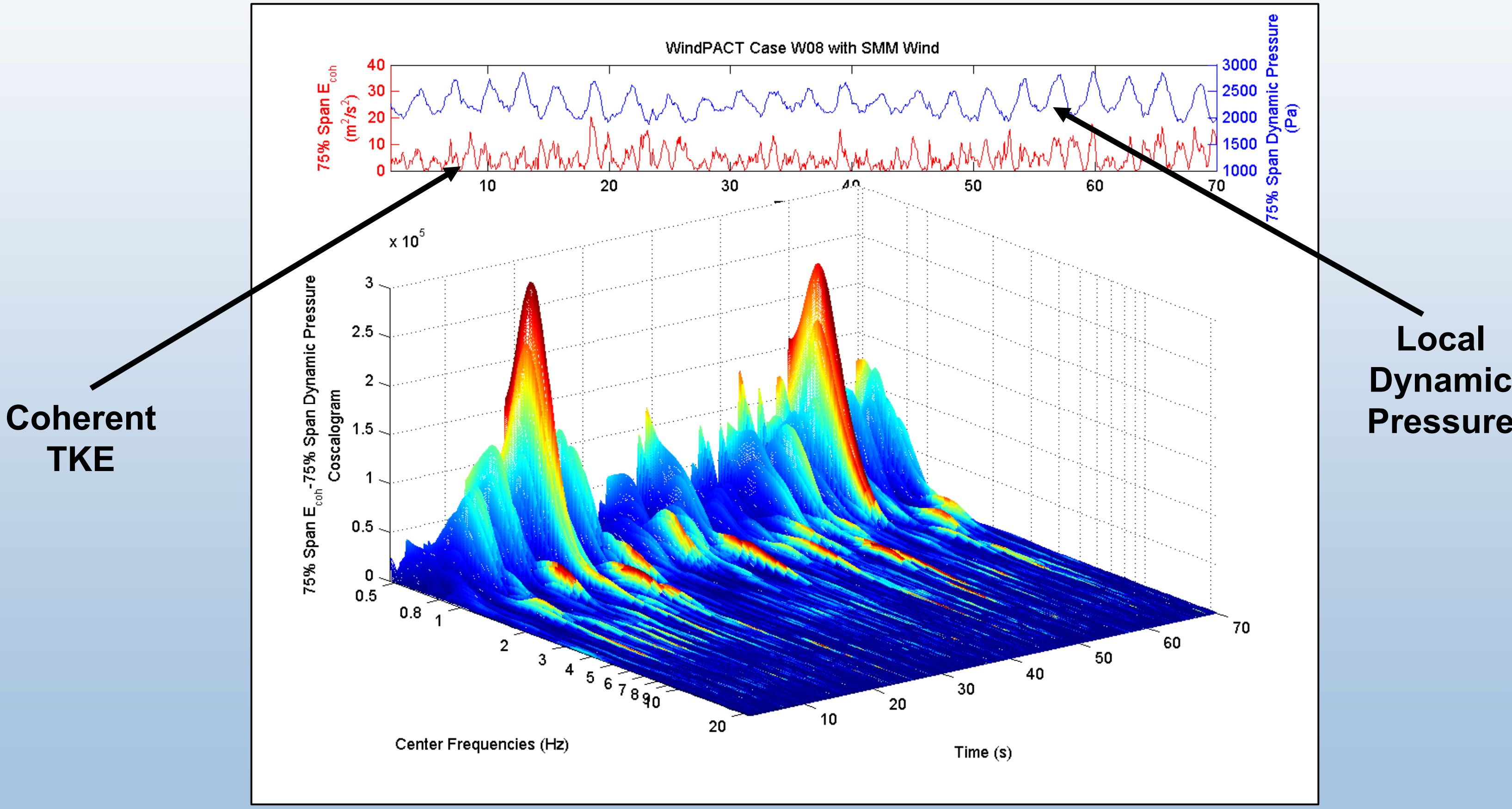
Energy Flux from Coherent Turbulence to Local Dynamic Pressure at 75% Span Blade Radial Position

IEC Normal Turbulence Model



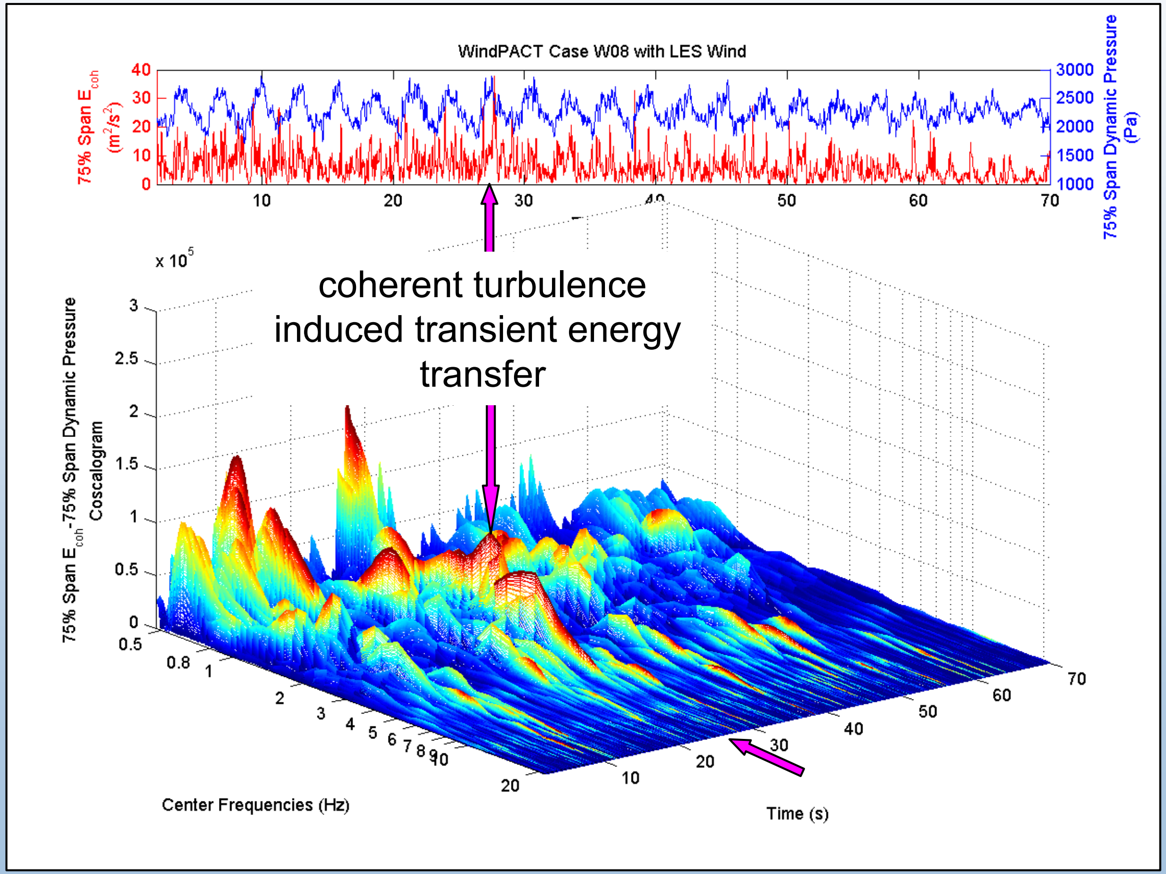
Energy Flux from Coherent Turbulence to Local Dynamic Pressure at 75% Span Blade Radial Position

Smooth Terrain Turbulence Model



Energy Flux from Coherent Turbulence to Local Dynamic Pressure at 75% Span Blade Radial Position

Breaking LES KH Billow



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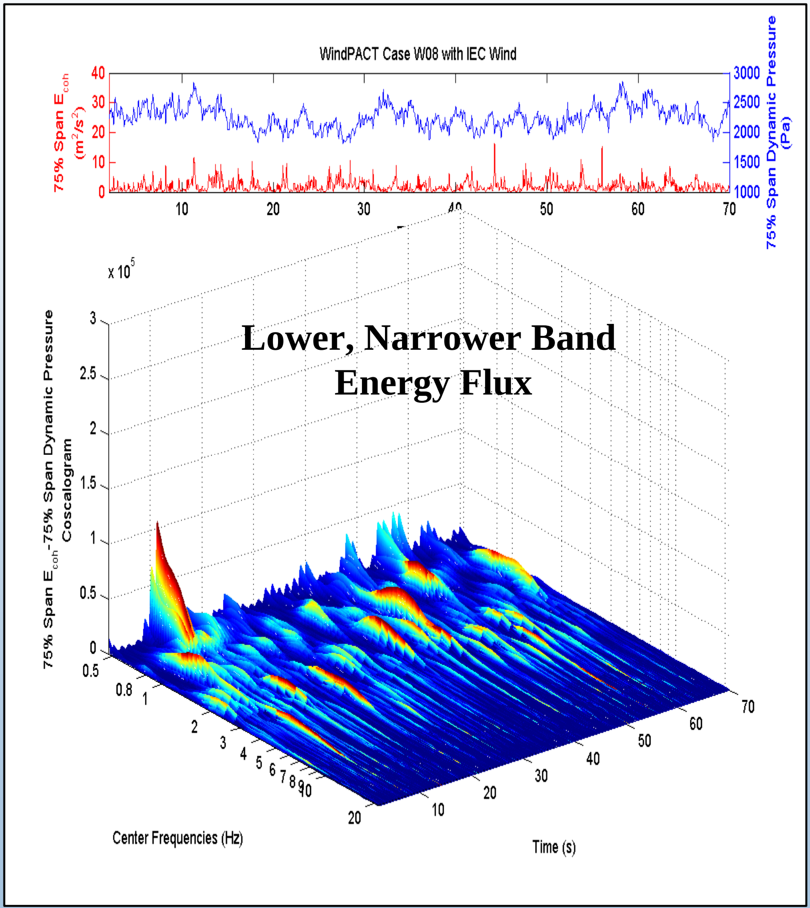
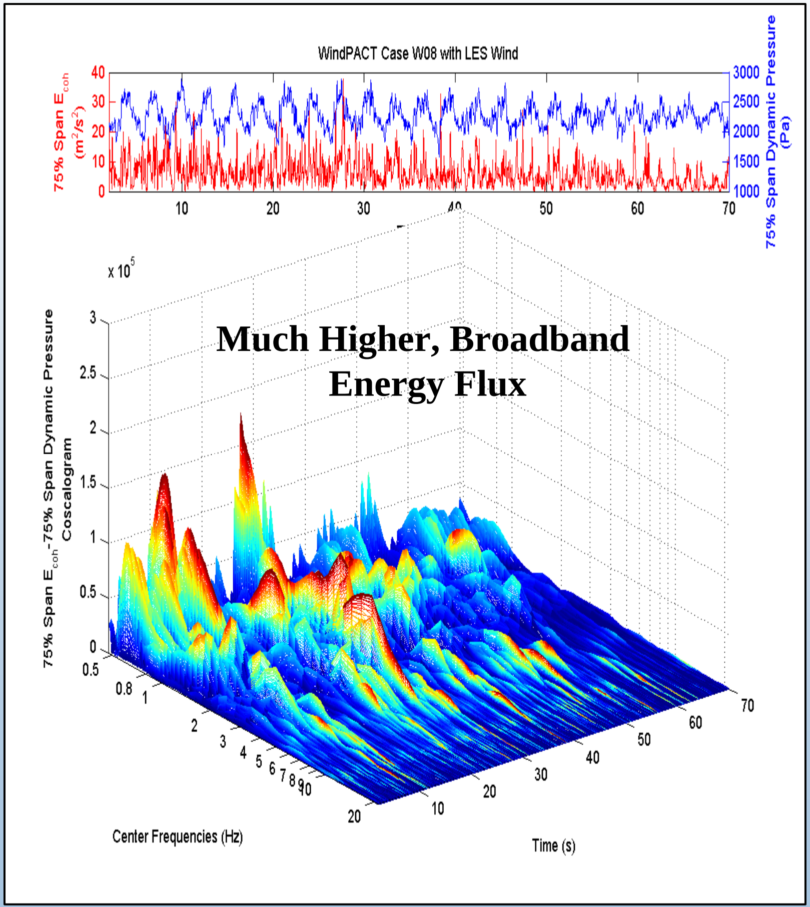
Comparison Between IEC NTM and KH Billow Excitation for WindPACT Turbine

IEC NTM



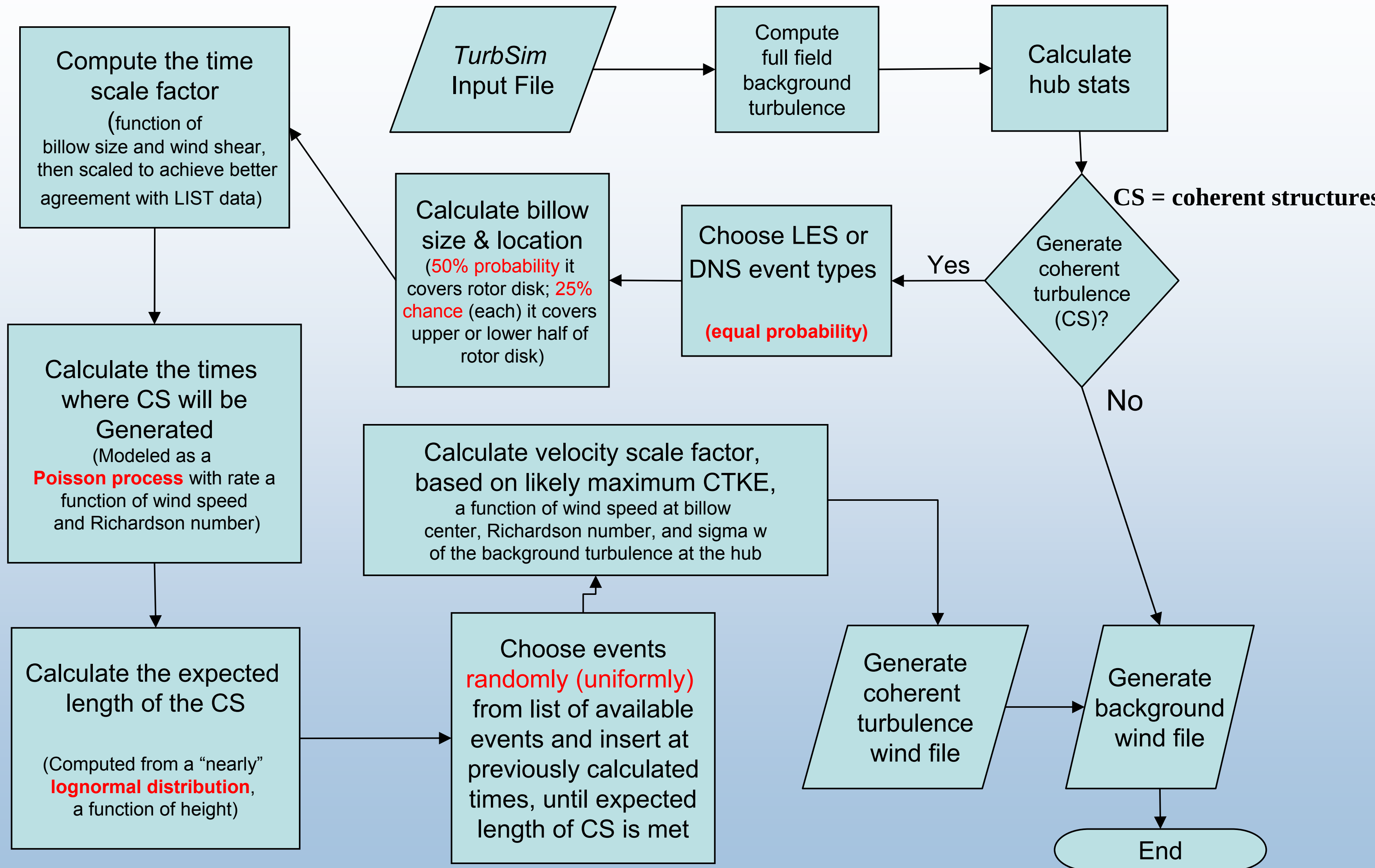
Breaking KH Billow



TurbSim Stochastic Inflow Turbulence Simulation Code

- Built on foundation of Paul Veers' original uni-component, adiabatic *SNLWIND* code using the spectral representation method
- Continues to provide the capabilities of the full vector, diabatic *SNLWIND-3D* and adiabatic *SNWind* codes
- Adds the capability of embedding coherent turbulent structures in a diabatic full-field flow with their spatiotemporal distribution modeled on breaking KH billows
- Provides five levels of randomization to provide a wide range of turbulent inflows that can be introduced to turbine models
- Coherent turbulence scaling is currently based on inflow measurements from the 5-sonic planar array upwind of the ART Turbine used in conjunction with the LIST Program (complex terrain)
- The Lamar 120-m tower data will later be used to provide scaling for a more realistic inflow for a Great Plains site with and without the presence of a low-level jet stream

TurbSim Flow Chart



Initial Conclusions & Current Thoughts

- Fourier-based inflow simulation techniques cannot adequately reproduce the transient, spatiotemporal velocity field associated with coherent turbulent structures
- Spatiotemporal turbulent structures exhibit strong transient features which in turn induce complex transient loads in wind turbine structures
- The encountering of patches of coherent turbulence by wind turbine blades can cause amplification of high frequency structural modes and perhaps increased local stresses which are not being adequately modeled with current inflow simulations